Cummins High Power Density Inverter

(Project ID:ELT281)

Santhosh Krishnamoorthi (PI)
Corporate R&T,
Cummins Inc.
santhosh.krishnamoorthi@cummins.com

Christina DiMarino
Dept. of Electrical and Computer Engg.,
Virginia Tech
dimarino@vt.edu

Shajjad Chowdhury
Electric Drives Research Group
Oak Ridge National Laboratory
chowdhuryms@ornl.gov

Kevin Bennion
Adv. Power Electronics and Electric Machines Group
National Renewable Energy Laboratory
Kevin.Bennion@nrel.gov

Objective

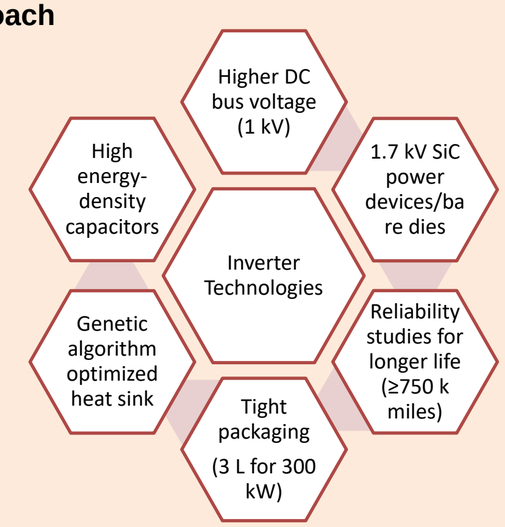
Develop and demonstrate a high-power density traction inverter for commercial vehicles to meet or exceed US DOE's 2025 targets:

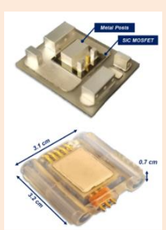
Targets		
Parameter	**US DOE 2025**	**Cummins Inverter**
Peak Power	≥ 100 kW	300 kW
Power Density	≥ 100 kW/L	≥ 100 kW/L
Volume	≤ 1 liter	≤ 3 liters
Operating DC Voltage	≥ 650 V	≥ 1000 V
Lifetime	≥ 300,000 miles	≥ 750,000 miles
Cost	≤ 2.7 $/kW	≤ 2.7 $/kW

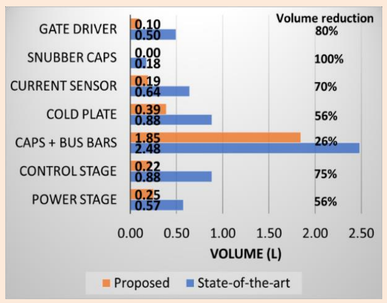
Relevance

- Platform for next-gen 1 kV WBG traction inverters
- Improve vehicle integration and lower Total Cost of Ownership
- Enable use of high-speed motor in Electric Commercial Vehicles
- Extend battery range through improved inverter efficiency
- Achieve more stringent commercial vehicle durability targets

Approach







Technical Accomplishments

- Identified multiple families of processors for control board development
- Selected potential topology and architecture options for the inverter
  - Potential 2-level, 3-level, Soft-switching and open-end winding topologies
- Acquired drive cycles for different MD applications for lifetime and reliability analyses
- Started selection of capacitor technologies and identified standards for EMI reduction

Challenges

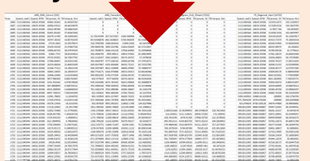
- Low yield of high-current SiC chips increases cost
- Higher EMI due to faster switching
- Possible delays in procurement of components
- Potential delays in the selection and procurement of the motor

Mitigation

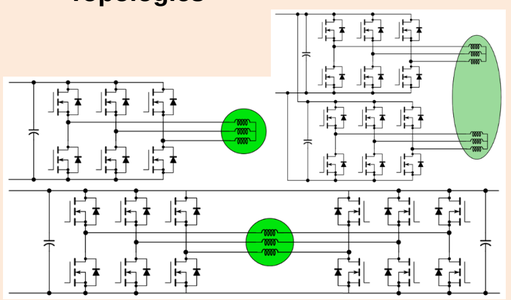
- Usage of SiC devices benefit the system and reduce overall costs
- Appropriate active gate drive and DC EMI filter designs to reduce effects of noise
- Early identification of delays and selection and procurement of components
- Use the developed motor models in motor emulator test cell

Medium-Duty Commercial Vehicle Applications

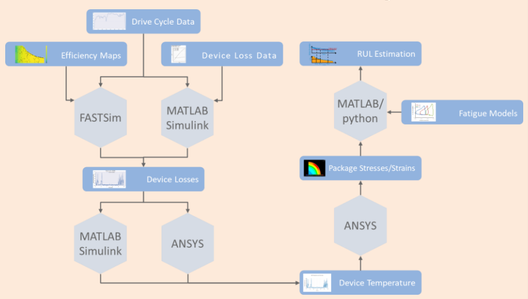
Drive Cycles



Topologies



Reliability Models



Timeline

Budget Period 1 (2021-2022)
Technology Research & Design

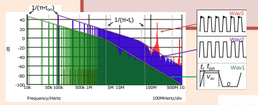
- H1: Select topology and component technologies
- H2: Complete modeling of components and demonstrate gate-drive power supply for a 3 L, 1 kV, 300 kW inverter

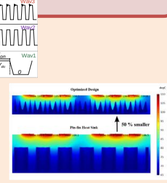
Budget Period 2 (2023)
Technology Development

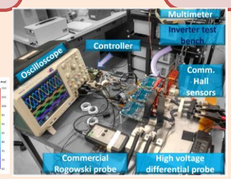
- H1: Fabricate and demonstrate inverter phase-leg with 99% efficiency
- H2: Complete Component Validations and Demonstration of 3 L Inverter prototype package integration

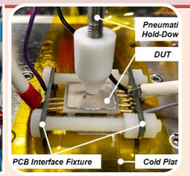
Budget Period 3 (2024)
Tech. Integration & Validation

- H1: Complete standalone inverter tests, lifetime assessments
- H2: Complete inverter test with motor-dyno and submit final reports and TCO for the inverter commercialization









Collaboration

- **Cummins**
  - Project Lead
  - Gather requirements, develop control board, develop software, build inverter package, lead motor testing, create final report and TCO
- **Virginia Tech**
  - Lead topology selection and determine the inverter system architecture
  - Develop power module, gate driver, sensors, fabricate & demonstrate power stage, develop lifetime models
- **Oak Ridge National Laboratory**
  - Support through development of critical components as a part of the inverter system
  - Develop capacitors, heat sink, EMI filters, characterize & test capacitors and heat sink, characterize & test caps and heat sink
- **NREL** *Transforming ENERGY*
  - Support development of the inverter through modeling and analysis
  - Develop thermal models & cooling system, evaluate, refine, & verify models, support packaging development

Future Work

- Finalize processor part for the control board and begin schematics design
- Select suitable topology for the inverter based on analysis
- Identify options for power modules or bare dies
- Select technology for capacitor based on the identified topology
- Determine losses based on the identified architecture and begin simulations for heat sink design